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V.J. Hernandez, Z. Pan, J. Cao, V.K. Tsui, Y. Bansal, S.K.H. Fong, Y. Zhang, M.Y. Jeon, S.J.B. Yoo
Department of Electrical and Computer Engineering, University of California Davis, 2064 EUII, Davis, CA 95616
Phone: (530) 752-7063 E-mail: yoo@ece.ucdavis.edu

Brian Bodtker, Steven Bond, William J. Lennon
Lawrence Livermore National Laboratory, 7000 East Avenue, CA 94550

Hank Higashi, Bryan Lyles, Robert McDonald
Sprint Advanced Technology Laboratories, One Adrian Court, Burlingame, CA 94010

Abstract: We demonstrate the first field trial of optical label-based wavelength switching and packet drop on 476.8km of the National Transparent Optical Network. Subcarrier multiplexed labels control a switch fabric that includes a tunable wavelength converter and arrayed waveguide grating router.

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Introduction

While subcarrier multiplexing (SCM) technology is effective in implementing optical label swapping [1,2], no field trial has been accomplished to date. All-optical header extraction and swapping using a fiber Bragg grating (FBG) has been shown to be dispersion and polarization insensitive [3]. Conventional circuit switching achieves traffic add-drop at wavelength granularity. Packet switching can achieve sub-wavelength granularity in add-drop. Using the National Transparent Optical Network (NTON), we achieve the first field demonstration of optical label-based wavelength switching and packet drop.

Experimental Set-up

We perform two experiments. The first tests reliability of SCM packets by transmitting and receiving over the NTON link on a loopback route. In the second experiment, SCM data packets are sent to the other end of the link for wavelength switching and packet drop. The undropped packets are returned to the source at a new wavelength. Both experiments use the layout in Fig. 1. Lawrence Livermore National Labs (LLNL) is the source node that transmits and receives the signal. NTON connects LLNL to Sprint Advanced Technology Laboratories (ATL), which serves as the switching node. In the first experiment, a fiber patch cord replaces the switching node, and this allows the signal to loopback to LLNL without any modifications. At the source node, a parallel bit error rate tester (ParBERT) creates a 1.6Gbps signal alternating between two 512-bit packets, called Payload 1 and Payload 2. Simultaneously, the ParBERT generates a 100Mbps signal consisting of two alternating 32-bit packets called Label 1 and Label 2. Label 1 and Label 2 align with Payload 1 and Payload 2, respectively. These are sent into a SCM transmitter. In the SCM transmitter, an RF circuit mixes the label with a 14GHz local oscillator (LO) that is multiplexed with the payload. The RF circuit includes low pass filters (LPF) and band pass filters (BPF) to limit bandwidth. The combined signal gets modulated onto a 1557.36 nm laser using a Mach-Zehnder $LiNbO_3$ modulator. The signal transmits through the lower leg of the San Francisco Bay Area NTON, which consists of 238.4km duplex single mode fiber. Six erbium doped fiber amplifiers (EDFA) are placed along the link for each direction. At the switching node, a circulator and fiber Bragg grating (FBG) separate the label from the payload. A burst mode receiver (BMR) performs optical-electrical conversion on the label and recovers the clock. The burst mode receiver is specifically designed to recover a clock from packetized (non-continuous) data. The converted label is sent into a field programmable gate array (FPGA) that controls a tunable laser (TL). If the FPGA detects Label 1, it sets the tunable laser to operate at 1546.0nm. If the FPGA detects Label 2, the laser operates at 1552.2nm. This laser serves as the switch wavelength of a semiconductor optical amplifier (SOA) using cross gain modulation. While the FPGA analyzes the label, the payload goes through 83.3 m of optical delay lines until it is sent into the SOA. At the SOA, the payload is switched to the operating wavelength of the tunable laser. This causes the original payloads to switch from 1557.36 nm to 1546.0 nm for Payload 1 and 1552.2 nm for Payload 2. These enter an 8x8 arrayed waveguide grating router, which demultiplexes the two wavelengths onto different ports. One port connects to the source node, sending back Payload 2. Payload 1 goes through a drop port at Sprint ATL.

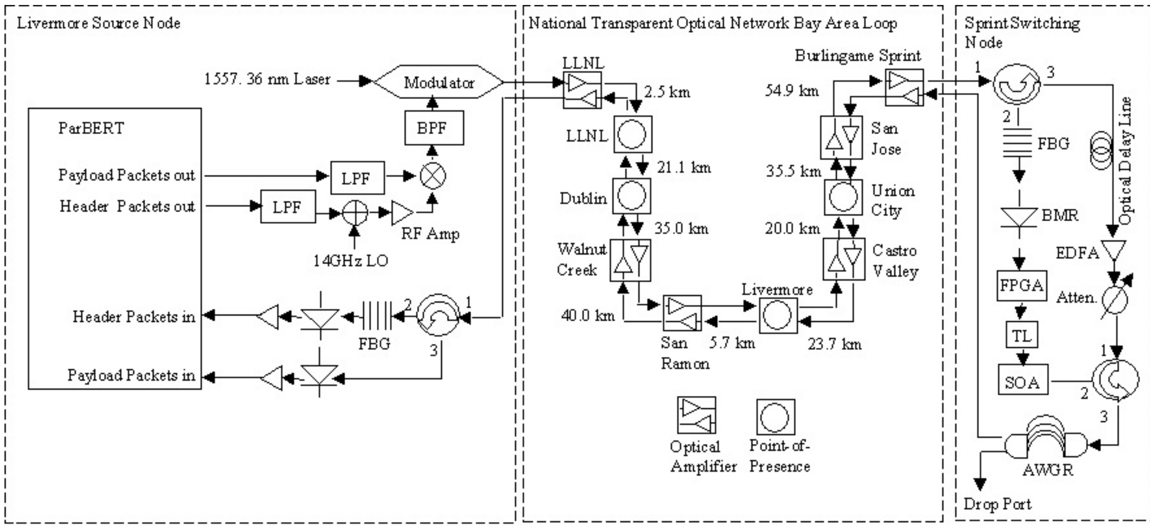

Fig 1: Experimental set-up. In the loopback experiment, a fiber patch cord replaces the Sprint Switching Node and connects the input to the output at Burlingame Sprint.

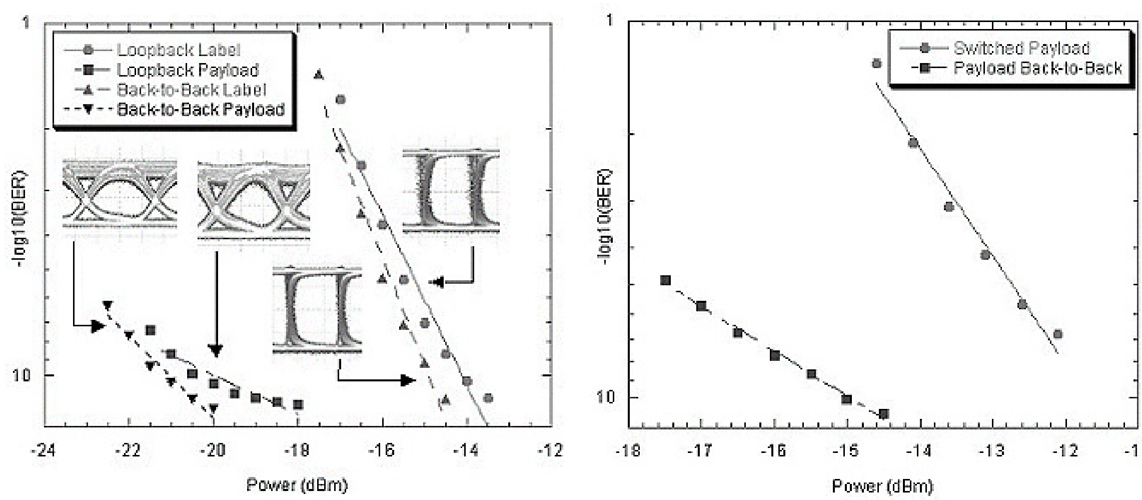

Fig. 2: BER curves from the loopback experiment (left) and switching experiment (right).

Results and Discussion

Figure 2 shows measured bit-error rate (BER) curves from the loopback experiment. The left plot compares the header and label in a back-to-back configuration and after 476.8km of fiber. The insets show measured eyes. The BER curve shows less than 2 dB power penalty after the loopback fiber transmission and the eyes show negligible distortion from dispersion. The right plot shows the BER for the received payload. There is a 5dB power penalty after wavelength switching. Figure 3 shows waveforms obtained at different points in the experiment. All traces use 500ns/div time scale unless stated otherwise. Trace 1a shows the payload and label extracted from the FBG at the switching node. Label packets (L1 and L2) and payload packets (P1 and P2) are aligned in time. The idle time between labels include stuffing bits of alternating 1's and 0's to aid the burst mode receiver. Trace 1b shows a close-up of Payload 2 at 5ns div. Trace 2 shows the switched payload after the SOA. The FPGA sets the tunable laser wavelength in response to the received label, and the tunable laser acts as the switching wavelength into the SOA. Since the tunable laser outputs two wavelengths at different powers, Payload 1 has a different power level from Payload 2. The signal is inverted due to the cross gain modulation of the SOA. After the SOA, the signal is sent into the AWGR for packet drop. Trace 3 shows the output at the return port of the AWGR. It contains only Payload 2 since Payload 1 has been dropped at another port. Payload 2 is sent back to the source node and the receiving RF amplifier inverts the signal to yield trace 4. Trace 4b shows a close up of Payload 2 at 5ns/div. Comparing to Trace 1b, we see that the bit pattern has been preserved through the switching and transmission.

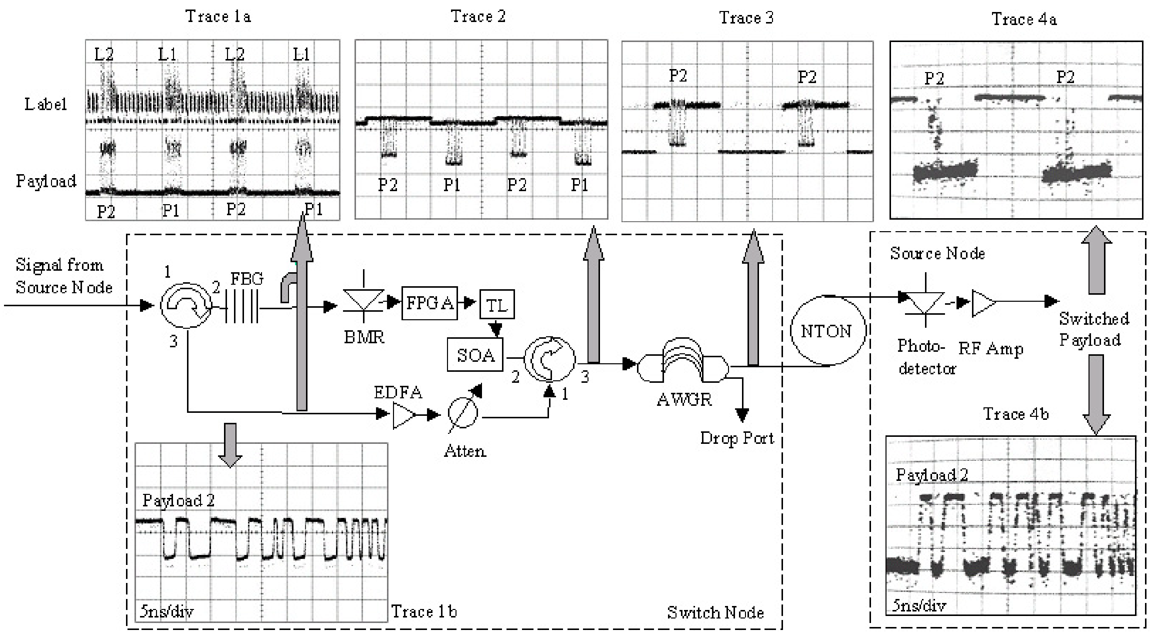

Fig 3: Waveforms obtained from switching experiment. Trace 1b and 4b compare payload bit patterns obtained by the switching node to the switched payload at the source node. Traces 1a,2,3,4a are scaled 500ns/div. Trace 1b,4b scaled to 5ns/div.

Conclusion

We have demonstrated for the first time in our knowledge optical label-based wavelength switching and packet drop over actual field fiber. We have shown SCM-formatted optical labeling transmission with less than 2dB power penalty for both label and payload over 476km of fiber. The optical label switching achieves packet drop and re-transmission of the remaining packet.

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